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CHATANIKA RADAR RESULTS DURING THE EXCEDE EXPERIMENT

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Stanford Research Institute
333 Ravenswood Avenue
Menlo Park, California 94025

September 1976

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results of the Chatanika DNA 617 Radar support coverage of the EXCEDE rocket experiment are presented, along with magnetometer and riometer data to give a more complete picture of ionospheric processes.

The EXCEDE rocket was launched at 0546:40 UT on 28 February 1976. The purpose of the experiment was to stimulate and measure shortwave infrared emissions under quiet ionospheric conditions. The Chatanika radar supported

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20. ABSTRACT (Continued)

the experiment in two ways--first, by monitoring the ionosphere and assuring that quiet ionospheric conditions existed at launch, and second, by providing continuous measurements of electron density near the rocket trajectory for comparison and correlation with rocket data.

Radar data yielded the following results:

- Background electron densities near the rocket trajectory were typically $< 3 \times 10^4$ el/cm^3 throughout the experiment.
- The rocket introduced some extraneous echoes into the radar data. These echoes were easily recognized and interpreted properly.
- Vector quantities measured just prior to the rocket launch were all small and somewhat noisy due to low SNR conditions.
- The radar data contained no evidence of electron density enhancements attributable to the electron-beam experiment aboard the rocket.

PREFACE

The author wishes to express his appreciation to John Kelly, who operated the Chatanika Radar during the EXCEDE experiment and to Mary McCready and Barbara Phillips, who reduced the on-line data.

Thanks also go to Drs. M. Baron, R. Vondrak, and P. Perreault and Mr. J. Spencer for many helpful suggestions in preparing this report.

Data used in connection with this report were obtained from the Geophysical Institute at Fairbanks, Alaska, from WDC-A for Solar Terrestrial Physics (Geomagnetism) Boulder, Colorado, and from Space Data Corporation, Phoenix, Arizona.

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ILLUSTRATIONS

I INTRODUCTION

The EXCEDE Experiment took place on 28 February 1976. The experiment payload was carried aboard a Sergeant rocket, launched from Poker Flat at 0546:40 UT. The rocket reached an apoges of 98.6 km at 158 s after launch and was above 70 km altitude during the time interval 82 to 236 s after launch. The purpose of the experiment was to stimulate and measure short-wave infrared (SWIR) emissions and to trace NO chemistry under quiet ionospheric conditions. The experiment payload included an electron gun, an ion mass spectrometer, and an assortment of photometers and radiometers.

The Chatanika radar was operated in support of the rocket experiment from 0455 UT to 0749 UT. From 0455 UT to 0539 UT and from 0559 UT to 0749 UT the radar antenna was operated successively at the three azimuth angles 29°, 154°, and 264°, and a constant elevation angle of 67°. Each antenna position was maintained for about three minutes, and a complete sequence of positions was accomplished in about ten minutes. An independent determination of the various background vector quantities measured by the radar was thus obtained every ten minutes.

From 0540 UT to 0556 UT the radar antenna was operated in an elevation scan mode, scanning between 45° and 90° elevation, with a constant azimuth angle of 29° (geomagnetic meridian). Each (one-way) elevation scan required a little less than three minutes. During the elevation scan mode, the radar obtained altitude-latitude maps of electron density in the geomagnetic-meridian plane north of the radar.

The Chatanika radar supported the rocket experiment in two ways. The real-time output of received power (proportional to electron density) was used to indicate proper launch conditions. The experiment required very quiet ionospheric conditions prior to launch. The radar provided real-time information on ionospheric electron density so that low electron density was ensured at launch. In addition, radar measurement data were fully processed later to provide information about the background state of the ionosphere before, during, and following the rocket flight, and to enable correlation of the various radar-derived quantities with rocket measurements.

II BACKGROUND MEASUREMENTS

A. Geomagnetic Conditions

Geomagnetic conditions during the launch period were very quiet. Figure 1 illustrates the College magnetogram during the launch window on 28 February. It can be seen that during the rocket flight, a very small eastward current system was present, indicated by the slight (5 to 10 γ) positive deflection of the geomagnetic H-component. Strong geomagnetic activity did not begin until about 0620 UT, when College passed under the strong eastward electrojet typical of the premidnight sector. This activity did not begin until well after the rocket flight was complete.

B. Absorption

Figure 2 illustrates absorption measured by the College riometer for the period 0440 UT to 0800 UT on 28 February. It can be seen that no significant absorption was observable until well after the rocket experiment was complete.

C. Electron Density

Figure 3 illustrates density[1*] contours for the period 0455 to 0749 UT. During the periods 0455 to 0539 UT and 0559 to 0749 UT (indicated by the solid lines), the contours were obtained by averaging over three successive antenna positions, yielding a time resolution of about ten minutes. During the period 0540 to 0556 UT (indicated by the

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* References are listed at the end of the report.

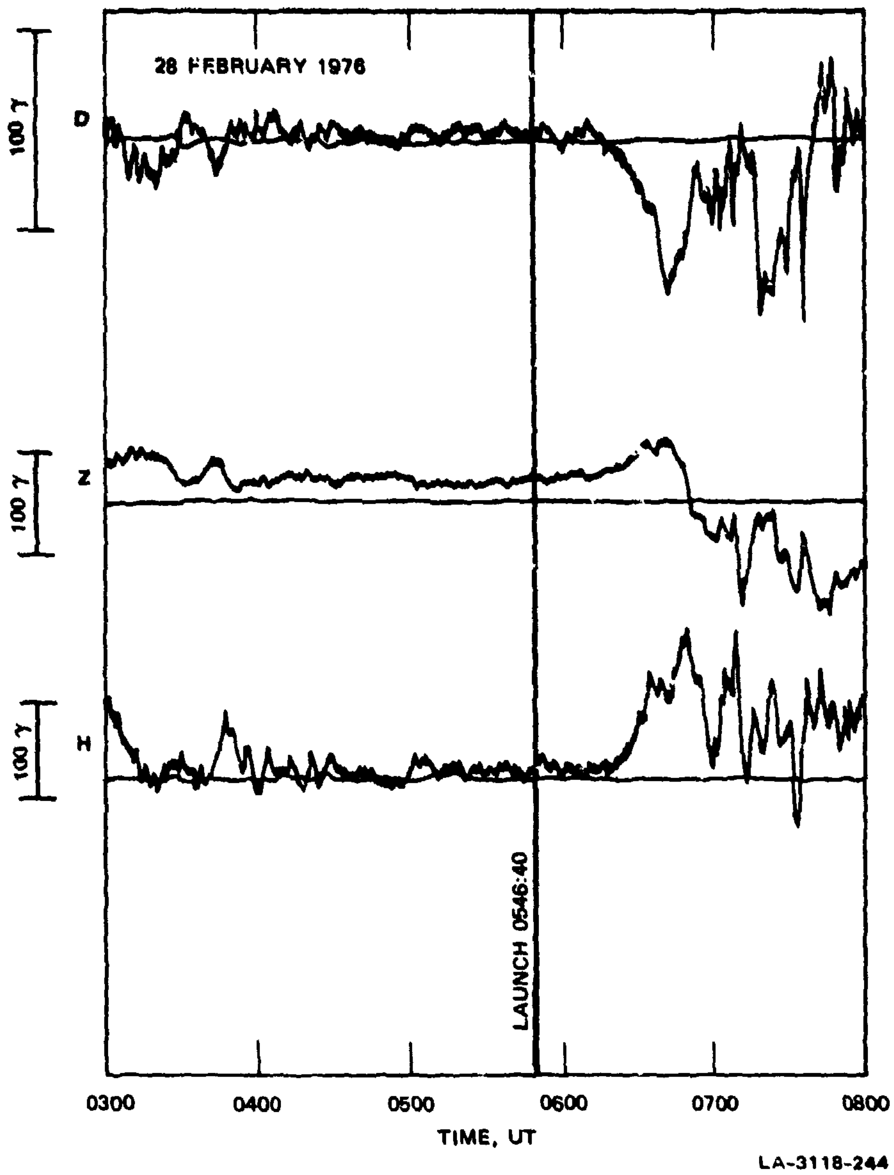

FIGURE 1 H-COMPONENT MAGNETOGRAMS ON 28 FEBRUARY 1976 FROM FOUR STATIONS DISTRIBUTED IN LATITUDE BUT IN THE SAME LOCAL TIME SECTOR AS THE ROCKET TRAJECTORY

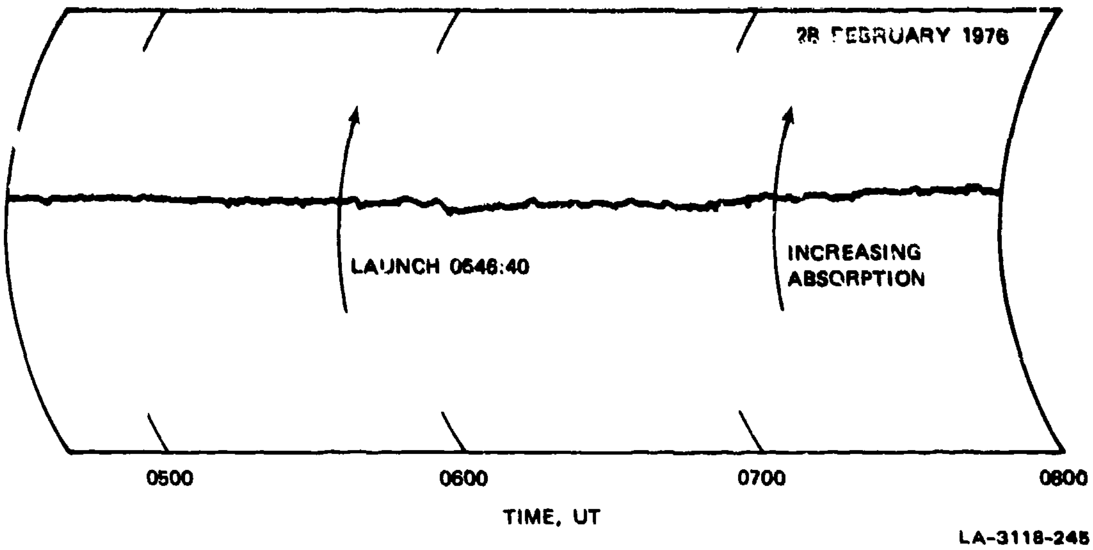

FIGURE 2 COLLEGE RIOMETER RECORD FOR 28 FEBRUARY 1976

dashed lines) while the antenna was scanning in elevation, the contours were obtained from data acquired while the antenna was pointed nearly vertical (> 85°).

The sensitivity of the radar for the E-region density measurements was about 10^4 el/cm^3. It can be seen that, until about 0600 UT, well after the end of the rocket experiment, averaged E-region densities above Chatanika were typically no greater than 3×10^4 el/cm^3. In terms of electron density, launch conditions were nearly ideal for the experiment.

The three-azimuth operating mode of the radar permitted an investigation of possible horizontal gradients in ionospheric electron density. During the period 0455 to 0539 UT no horizontal gradients were observed by the radar. Any horizontal gradients that might have been present during this period were either below the sensitivity threshold of the radar or were transient with time scales shorter than the ten-minute resolution limit of the three-position scan sequence.

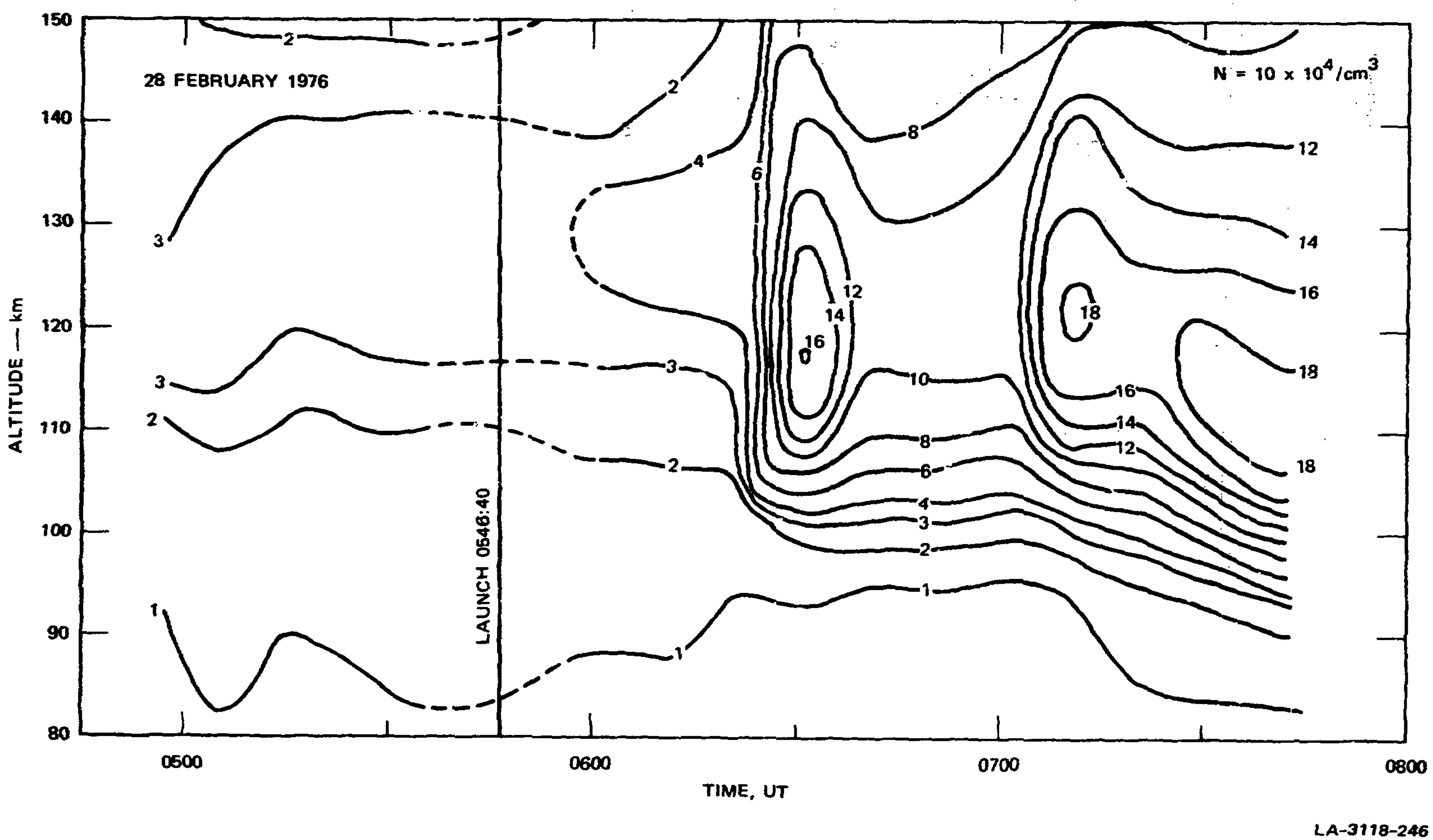

FIGURE 3 BACKGROUND CONTOURS OF ELECTRON DENSITY FOR THE EXCEDE EXPERIMENT ON 28 FEBRUARY 1976

At about 0620 UT, long after the rocket experiment ended, E-region densities increased rapidly and remained high through the end of the data run. This observation is consistent with the rapid increase in geomagnetic activity illustrated in Figure 1, and is indicative of an onset of auroral precipitation. Densities observed after 0620 UT are typical of auroral-oval conditions.

D. Height-Integrated Conductivities

Figure 4 illustrates the Hall and Pedersen conductivities measured during the experiment.[2] Hall conductivity is shown by the dashed line and Pedersen conductivity by the solid line. Conductivities were not calculated between 0539 and 0559 UT while the antenna was operating in an elevation scan mode.

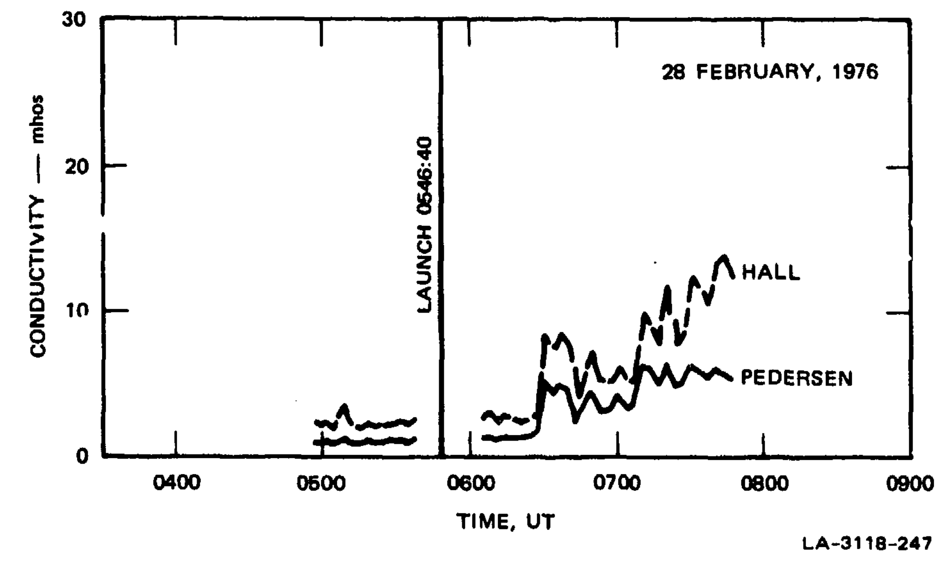

FIGURE 4 HEIGHT-INTEGRATED CONDUCTIVITIES FOR THE EXCEDE EXPERIMENT ON 28 FEBRUARY 1976

As expected, both conductivities, which are proportional to electron density, were quite low until about 0620 UT when electron density increased. Before 0620 UT, the Hall and Pedersen conductivities remained in the ranges 2 to 3 and 1 to 2 mhos, respectively. After 0620 UT, Hall conductivity increased to the range 4 to 14 mhos, and Pedersen conductivity increased to the range 3 to 6 mhos.

E. Electric Field

The ionospheric electric field[2,3] is shown in Figure 5. The geomagnetic north-south component is shown by the dashed line, and the east-west component by the solid line. No measurements of electric field were made from 0539 to 0559 UT, while the antenna was operating in an

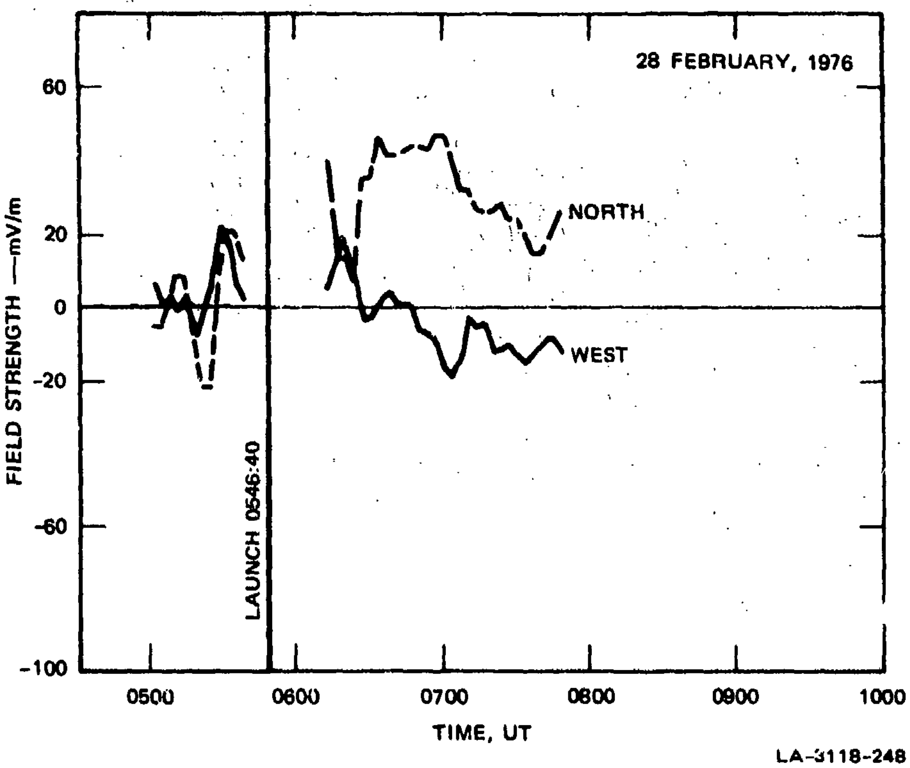

FIGURE 5 ELECTRIC FIELD FOR THE EXCEDE EXPERIMENT ON 28 FEBRUARY 1976

elevation scan mode. In addition, electric field values obtained during periods of low electron density exhibit a great deal of scatter as a result of low SNR. In order to diminish the large random fluctuations in transport quantities associated with low SNR, spectral data were averaged over range gates 2, 3, and 4 (165, 225, and 285 km altitude) during the period 0455 to 0539 UT. At other times, transport calculations were based on data taken from range gate 3, at 225 km altitude.

The height-averaged electric fields presented for the prelaunch period suggest that the period of the rocket experiment was typified by small (≤20 mV/m) north-south and east-west components of electric field.

Beginning with the onset of auroral activity at about 0620 UT, the electric field components took on a more defined behavior. A 40-mV/m northward component became evident by about 0630 UT, gradually decreasing to about 20 mV/m by 0800 UT. During the same period a smaller westward component appeared and showed a gradual increase to about 10 mV/m at 0700 UT, remaining fairly steady through 0800 UT. The behavior of the electric field after 0620 UT is associated with an eastward electrojet, and is thus consistent with the geomagnetic conditions discussed in Section II-A.

F. Neutral Wind

The E-region horizontal neutral wind was computed using the method described by Baron and Chang.[2,3] The neutral wind computed by this method represents a weighted average over 40 to 50 km of altitude, but the radar measurements are heavily weighted toward the altitude of peak electron density. As the altitude of the peak density changes, apparent temporal changes in neutral wind may simply represent changes in the

altitude at which the neutral wind is being sampled. In addition, the accuracy of radar-derived neutral wind is strongly dependent on SNR, and accuracy becomes poor at low SNR.

Figure 6 shows the E-region neutral-wind estimates as a function of time. No measurements of neutral wind were made from 0539 to 0559 UT,

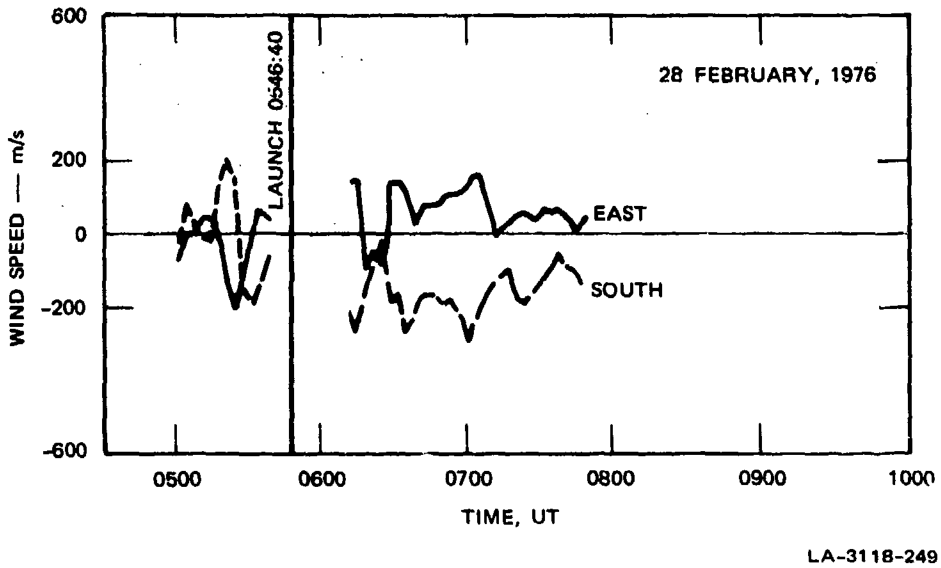

FIGURE 6 HEIGHT-AVERAGED E-REGION NEUTRAL WIND FOR THE EXCEDE EXPERIMENT ON 28 FEBRUARY 1976

while the antenna was operating in an elevation-scan mode. Neutral-wind calculations for the prelaunch period are based on height-averaged electric fields, described in Section II-E. The neutral-wind estimates between 0620 and 0800 UT are probably the most reliable because the SNR was high and the altitude of maximum ionization was relatively constant. During this time period there was a southward component of about 190 ± 100 m/s and an eastward component varying from 0 to 150 m/s. The magnitudes of both components tended to decrease after about 0700 UT.

G. Height-Integrated Current Density

Figure 7 illustrates height-integrated current density components for the period of radar operation.[4] No measurements of current density were made from 0539 to 0559 UT, while the radar antenna was operating in an elevation-scan mode.

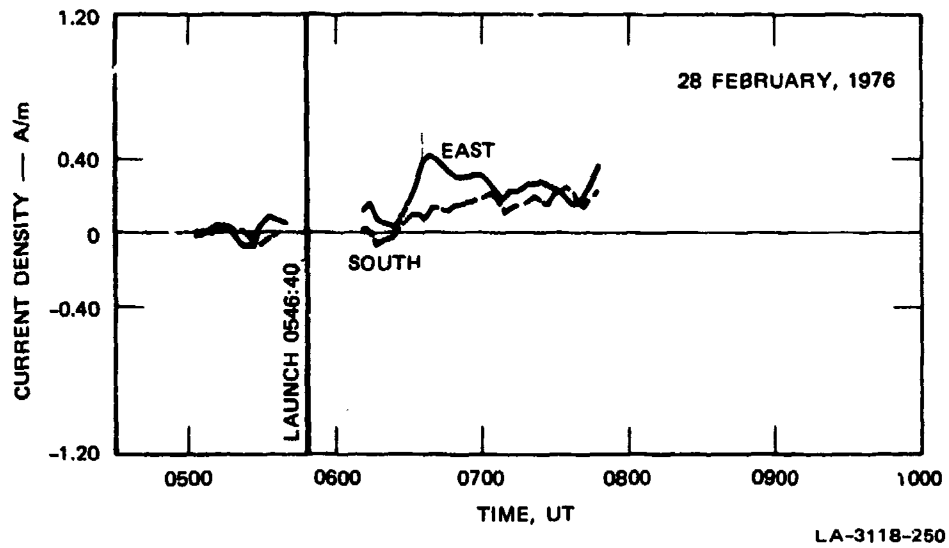

FIGURE 7 HEIGHT-INTEGRATED CURRENT DENSITY FOR THE EXCEDE EXPERIMENT ON 28 FEBRUARY 1976

Prior to 0620 UT, current density was very low, consistent with the small conductivities observed during this period (see Figure 4). Beginning about 0620 UT, current density exhibited a northeast direction with both northward and eastward components increasing from 0 to about 300 to 400 mA/m during the period of data acquisition.

H. Energy Deposition

The calculated energy deposited from joule heating is shown in Figure 8.[2] No calculations of joule heating were made from 0539 to 0559 UT while the antenna was operating in an elevation scan mode. Prior to 0620 UT, computed values of joule heating dissipation were small. At about

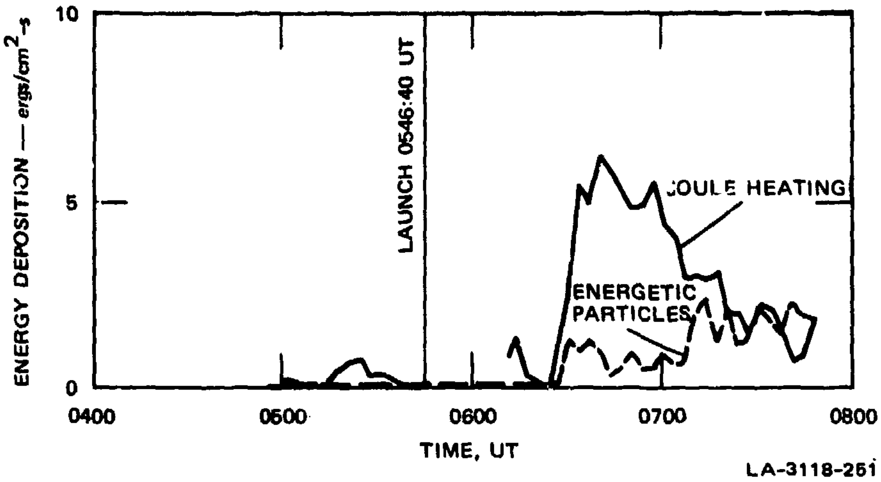

FIGURE 8 JOULE HEATING AND ENERGETIC PARTICLE CONTRIBUTIONS TO TOTAL ENERGY DEPOSITION FOR THE EXCEDE EXPERIMENT ON 28 FEBRUARY 1976

0620 UT, joule heating dissipation increased rapidly to about 6 ergs/cm^2-s and then decreased gradually to the range 1 to 2 ergs/cm^2-s at the end of the data run.

Figure 8 also shows the rate of energy deposition by the precipitating electrons as a function of time.[5,6] Prior to 0620 UT, energy deposition by precipitating electrons was virtually zero, a result consistent with the extremely low electron density measured during this period (see Figure 3). At the onset of auroral activity after 0620 UT, energy deposition due to particle precipitation increased to a moderate level of 1 to 2 ergs/cm^2-s.

Total energy deposition due to both sources was probably less than 1 erg/cm^2-s during the period of the rocket experiment.

III CORRELATED MEASUREMENTS

A. General

The decision to commit the EXCEDE rocket for a launch marked the completion of the first task of the Chatanika radar--viz., determining that low electron densities existed in the D- and E-regions. Shortly before launch, the operation of the radar antenna was changed from a three-azimuth-position mode to an automatic elevation scan mode. The azimuth of the antenna was fixed in the geomagnetic meridian (29° east of north). At this azimuth the antenna was scanned in elevation between 45° and 90° elevation, requiring about 2 min 40 s for each one-way scan. Each scan provided a two-dimensional (altitude vs ground range) cross-sectional map of the auroral ionosphere. Elevation scans were made before, during and after the passage of the rocket through the ionosphere, thus permitting an evaluation of the effects of the rocket experiment on the local ionosphere. A total of five elevation scans were made, after which the operation was changed back to a three-azimuth-position mode.

B. Separation Between Rocket and Radar Beam

At the time of the launch (0546:40 UT), the radar antenna scan was moving northward in an elevation scan. By the time the rocket reached ionospheric heights, however, the radar scan had moved well north of the rocket position and was nearly ready to reverse to a southward scan. The most interesting possibilities for correlation of radar and rocket data thus occurred on the second scan (0548:47 to 0551:23 UT).

Figure 9 illustrates the geographic ground track of the rocket, with various times after launch indicated along the curve. Figure 9 also illustrates the geographic ground track of the intersection between the radar beam and the instantaneous altitude of the rocket. Corresponding to each of the time-after-launch points along the rocket ground track is a point indicating the instantaneous altitude of the rocket.

Figure 9 shows the radar-beam ground track in the geomagnetic meridian of Chatanika and also suggests that the closest horizontal distance between the rocket and the radar beam was about 7 km, occurring about 190 s after launch.

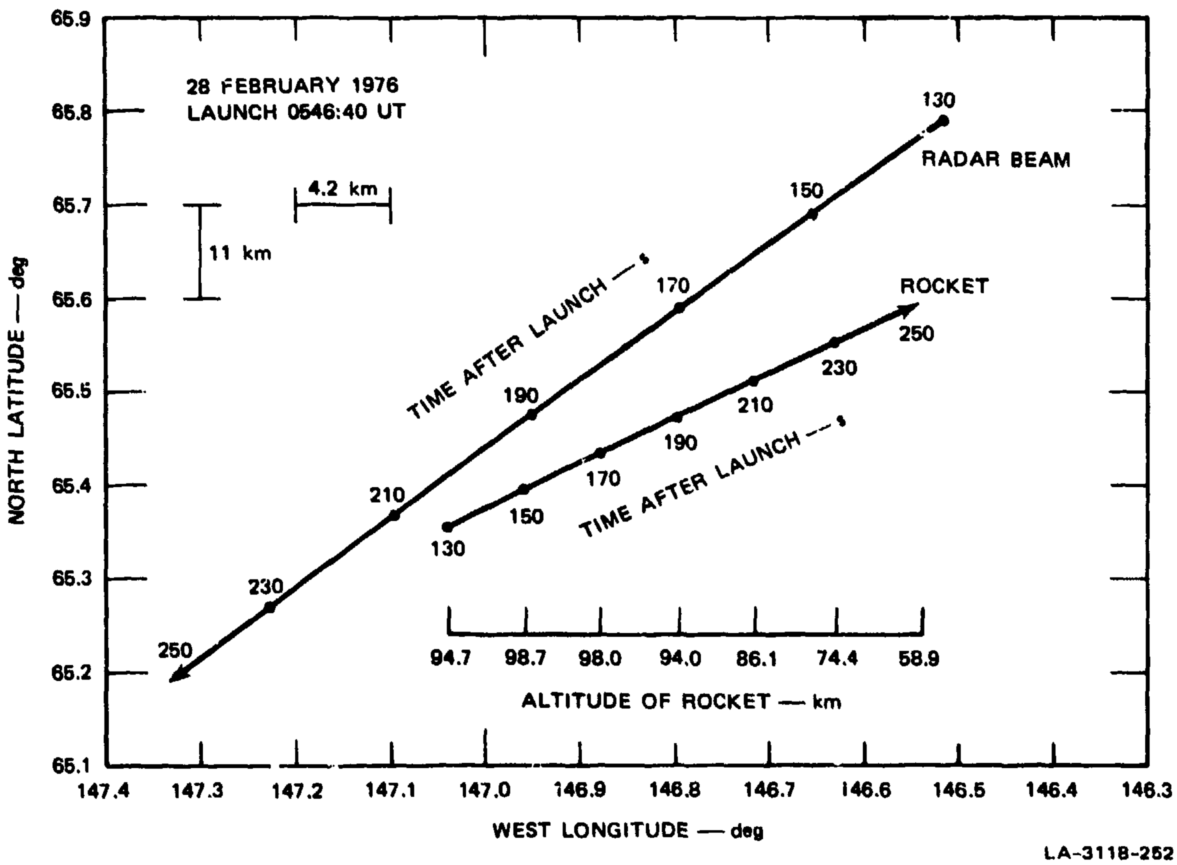

FIGURE 9 ILLUSTRATION OF HORIZONTAL SEPARATION BETWEEN THE RADAR BEAM AND THE ROCKET FOR THE EXCEDE EXPERIMENT ON 28 FEBRUARY 1976

C. Electron Density

As stated earlier, elevation scans were made before, during, and after the time that the rocket was in the ionosphere. Radar data acquired during each scan permitted the construction of a two-dimensional (altitude vs ground range) map of electron density within the geomagnetic meridian of the radar. The meridian of the radar was close, but not coincident with the vertical plane of the rocket trajectory (see Figure 9). As a result of the closeness, radar measurements provided a good indication of conditions near the rocket.

Figure 10 illustrates electron density contours measured just before the rocket reached the ionosphere. It can be seen that densities are very low, typical of post-sunset, pre-auroral conditions. Because of the low densities, it was necessary to average the data in some way in order to enhance SNR and yield smooth contours. The contours in Figure 10 were obtained from data averaged over 6 s (about 1.5° in scan) and three range gates (13.5 km range). Associated with the 6-s integration is a sensitivity threshold of about 3×10^4 el/cm^3; thus we are unable to provide contours of electron density $<3 \times 10^4$ el/cm^3. The contours indicate a maximum density of 6×10^4 el/cm^3 occurring in the altitude range 120 to 150 km. More importantly, however, at all altitudes below rocket apogee, measured electron densities were less than 3×10^4 el/cm^3.

Figure 11 illustrates contours of electron density obtained during the second elevation scan, while the rocket was in the ionosphere. It can be seen that the tenuous ionization layer at 120 to 150 km altitude was still present and not significantly changed from the first scan. In addition, a significant enhancement was observed in the altitude range 85 to 105 km.

It is easy to show that the enhancement is an artifact associated with the rocket. This can be shown as follows. Figure 11 illustrates

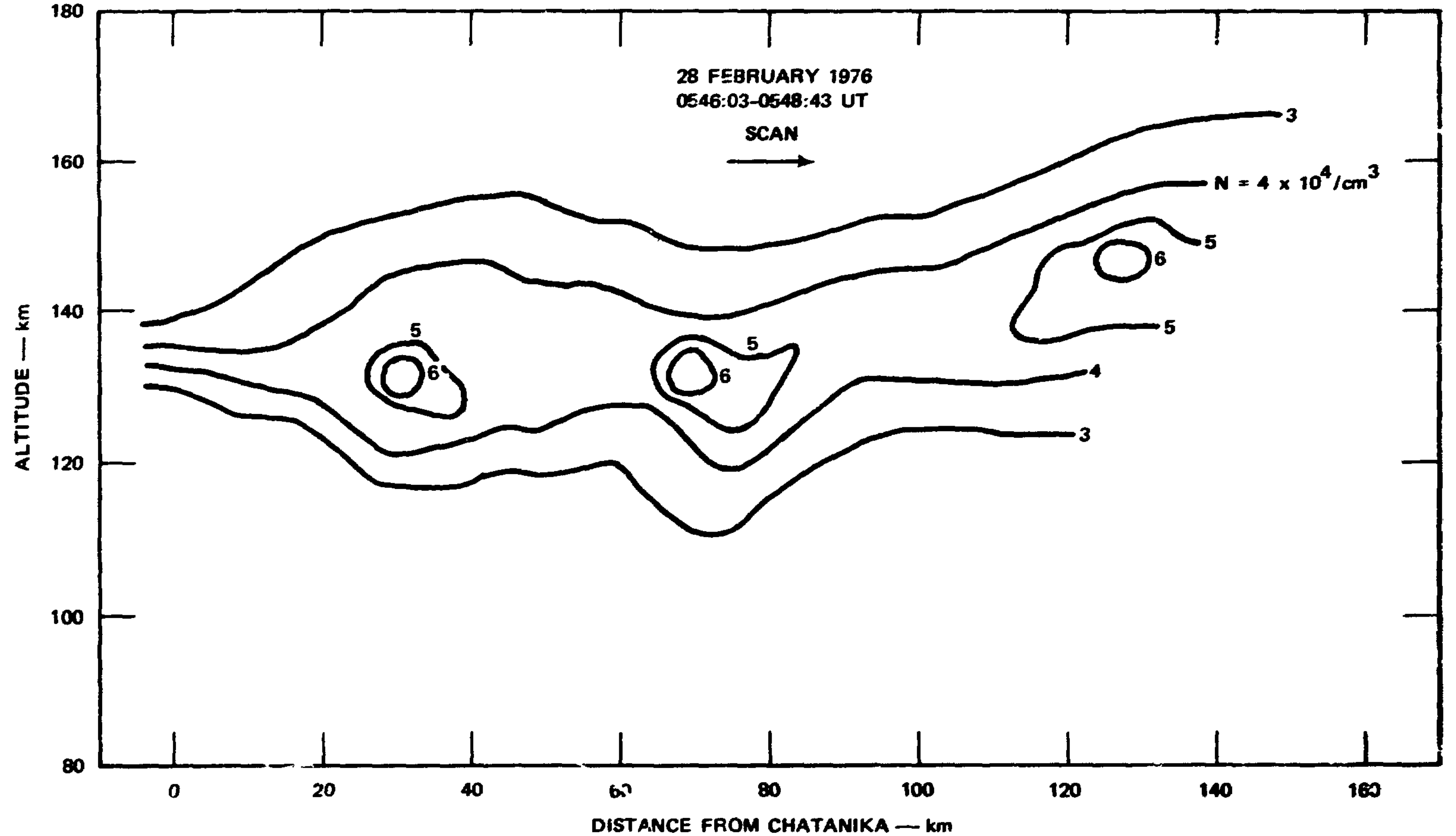

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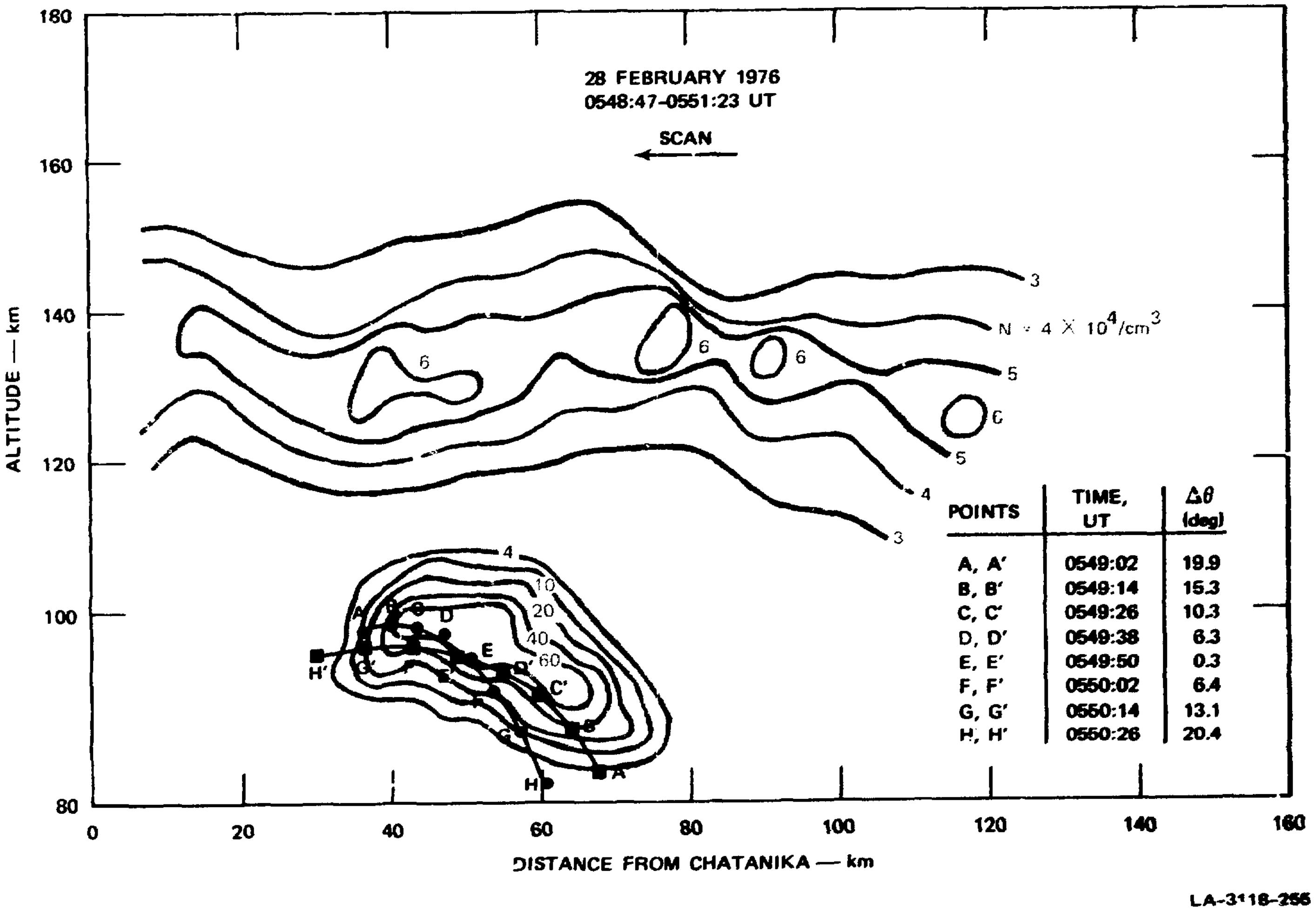
FIGURE 10 MERIDIAN-PLANE MAP OF ELECTRON DENSITY CONTOURS BASED ON RADAR OBSERVATIONS FROM 0546:03 TO 0548:43 UT, 28 FEBRUARY 1976



POINTS	TIME, UT	$\Delta\theta$ (deg)
A, A′	0549:02	19.9
B, B′	0549:14	15.3
C, C′	0549:26	10.3
D, D′	0549:38	6.3
E, E′	0549:50	0.3
F, F′	0550:02	6.4
G, G′	0550:14	13.1
H, H′	0550:26	20.4

FIGURE 11 MERIDIAN-PLANE MAP OF ELECTRON DENSITY CONTOURS AND ROCKET-INDUCED ECHOES BASED ON RADAR OBSERVATIONS FROM 0548:47 TO 0551:23 UT, 28 FEBRUARY 1976. Details are given in the text.

two curves plotted through the enhancement, one connecting the points A, B,...H and the other, the points A′, B′,...H′. The points A, B, ...H represent the locations (altitude, ground range) of the rocket at each of the corresponding times listed on the table in Figure 11. The points A′, B′, ...H′ represent locations (altitude, ground range) of points on the main beam of the radar having the same range as the points A, B, ...H. That is, A′ has the same radar range as A; B′ has the same radar range as B; etc. The curve A, B, ...H thus represents a two-dimensional description of the actual trajectory of the rocket, and the curve A′, B′, ...H′ represents a two-dimensional description of the locus of radar echoes associated with the rocket.

The next point to consider is that the antenna gain of a radar is a maximum on the axis of the main beam and decreases with increasing angle off-boresight. One would thus expect the greatest signal return from a moving target when the target position is closest to radar boresight. The table in Figure 11 lists off-boresight angle, $\Delta\theta$, of the rocket corresponding to each of the positions A, B, ...H. It can be seen that $\Delta\theta$ was a minimum at the time corresponding to the points E and E′, where the apparent enhancement is greatest, and that enhancements were observed for values of $\Delta\theta$ as great as 20°.

From these observations it seems clear that the enhancement was not due to electron density, but was rather the result of signal echoes from the rocket. It is interesting to note the sensitivity of the radar to rocket echoes, inasmuch as the gain of the Chatanika radar antenna at 20° off-boresight is 45 dB below boresight gain.

Figure 12 illustrates contours of electron density obtained during the third elevation scan, which took place after the rocket had exited from the ionosphere on its downleg. It can be seen that a tenuous layer of ionization is still present in the altitude range 120 to 140 km.

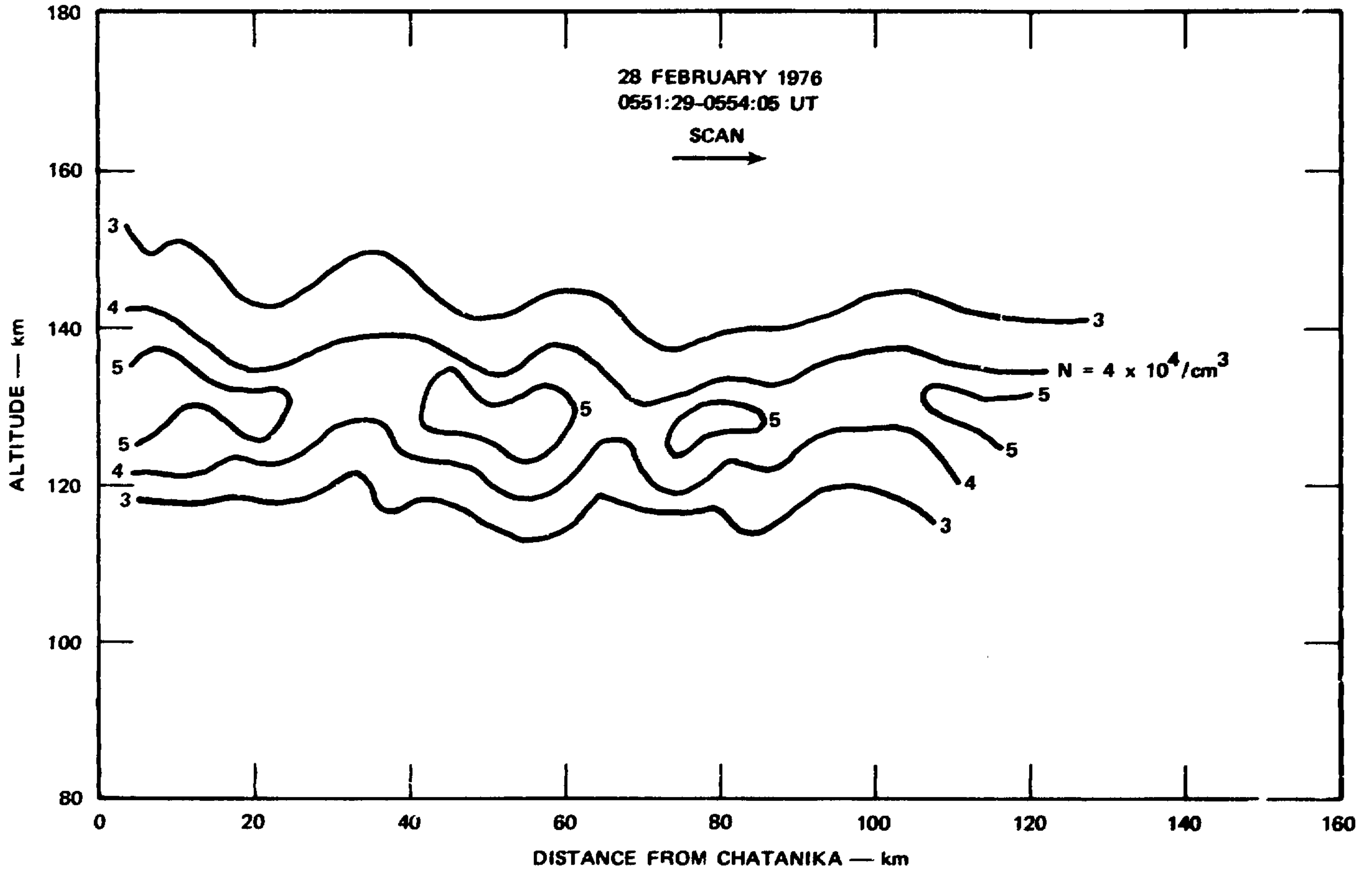


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FIGURE 12 MERIDIAN-PLANE MAP OF ELECTRON DENSITY CONTOURS BASED ON RADAR OBSERVATIONS FROM 0551:29 TO 0554:05 UT, 28 FE[illegible]ARY 1976

Ionization in this region appears comparable to that observed during the first and second elevation scans. There has been, if anything, a slight decrease in density in this region. In particular, there is no evidence of any effect induced by the EXCEDE experiment.

The large echo associated with the rocket observed during the second elevation scan had completely disappeared by the time of the third scan. This is not surprising, since even if some of that echo had been due to artificial ionization--i.e., sheath or exhaust effects--the recombination rates at the observed altitudes should easily have eliminated any residual effects within a few tens of seconds after removal of the source. Finally, we note from Figures 10 to 12 that ionization in the vicinity of the rocket trajectory was fairly constant in time and space during the eight-minute period encompassing the rocket flight.

IV SUMMARY AND CONCLUSIONS

The EXCEDE experiment took place on 28 February 1976, beginning at 0546:40 UT. As required by the experiment, ionospheric conditions were very quiet at the time of launch.

The Chatanika radar began operating in a three-azimuth-position mode about an hour before the launch, in support of the experiment. Prior to launch, the radar provided continuous real-time indications of D- and E-region ionospheric density near the expected rocket trajectory, and thus ensured that quiet conditions existed before the commitment to launch the rocket was made. Just before launch, the radar operating mode was changed to provide elevation scans in the geomagnetic meridian of the radar, in order to provide closer correlation with rocket measurements. After completion of the rocket flight, the radar was returned to a three-azimuth-position operating mode, and additional data were acquired for about two more hours.

Radar data acquired before, during, and after the rocket flight were later processed and are presented in this report. In general, the following results were obtained:

- Background electron densities in the vicinity of the rocket trajectory were typically $< 3 \times 10^4$ el/cm^3 before, during, and after the rocket experiment. This condition did not change until several tens of minutes after the completion of the rocket flight.
- The rocket introduced some extraneous echoes into the radar data. These were easily recognized and interpreted properly.
- Vector quantities measured by the radar just prior to the rocket experiment were all small and somewhat noisy (due to low-SNR conditions).

* Beginning about 0620 UT, well after the completion of the rocket experiment, aurorally active conditions began, characterized by increased densities, conductivities, electric fields, current densities, and energy deposition. These conditions appear typical of a premidnight onset of an eastward electrojet within the auroral oval.
* The radar data contained no evidence of electron density enhancements attributable to the electron-beam experiment aboard the rocket.

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